Chapter 3 Issues Facing Forest Management in Canada, and Predictive Ecosystem Management Tools for Assessing Possible Futures

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Abstract

Forestry has been changing throughout its history in response to changing needs of human populations and changing supplies of forest resources and values to satisfy these needs. Canadian forestry has undergone a series of changes that reflect much of the global pattern of the change in this human activity, and considering the extent and diversity of Canadian forests, they are now amongst the best managed in the world. However, change continues in the face of continuing challenges and environmental, social and economical issues. Some of these are discussed briefly in this chapter. We also describe one contribution to the resolution of some of these issues in forestry: hybrid simulation, ecosystem management models that span from individual trees (for complex mixed stands) to landscapes of various sizes. The family of models that is briefly described is based on the FORECAST model. Emphasis is given to the LLEMS landscape model.

Keywords

Canada, forestry, issues and challenges, ecosystem modeling, FORECAST, LLEMS.

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3.1 A brief history of forestry in Canada

As in most forested countries, forestry in Canada is continually changing. In contrast to many countries the history of this change is relatively short. A significant proportion of the forest in the northern parts of many Canadian provinces remains in a relatively "natural" (pre-European colonization) condition, whereas many forests in the south have been significantly changed. This reflects timber harvesting, clearance for agriculture, fire control, a reduction in the historic influence of our "First Nations" (the pre-European inhabitants of Canada), and, in some areas, oil and gas exploration. Any discussion of current Canadian forest management and possible directions for future change should be framed by an understanding of this history and its variation across this vast country. The objective of this chapter is to consider some of the key issues facing Canadian forestry, and to explore one example of the type of ecosystem-based decision support tool that we believe is a pre-requisite for achieving sustainable forest ecosystem management in the context of these issues. A review of other types of forest models can be found in Messier et al. (2003).

Before looking briefly at Canada's forest history it is useful to consider the more general patterns of development in the relationship between people and forests that have occurred at various times and places around the world. Early human societies simply exploited forests for a wide variety of values — both timber and non-timber. Such exploitation[1] was sustainable because the rate of utilization was less than the rate of natural replacement. This reflected one or more of: low human populations, low per capita demand for the resource or value, low levels of technology that limited the rate of consumption, or the rapid renewal of the resource or value by natural processes (Salim and Ullsten 1999). As populations and the power of technology increased, human utilization of forest resources began to exceed the supply and rate of renewal, at which time the exploitation became non-sustainable and the supply declined. Human response was either to become nomadic to secure resources from uninhabited areas, or, where this was not possible, to invoke taboos and belief systems (e.g. religious edicts) to protect local forests. Alternatively, remote forest areas were colonized by force. Much of the European colonial period involved exploitation of timber in other countries for ships to maintain trade and military superiority. When these mechanisms failed to ensure desired future supplies, forest management evolved (Winters 1972).

Early forest management has always tended to be politically or administratively organized, rather than be based on recognition of the spatial and temporal diversity in the ecological character of forests. It tended to be based on regulation of an inventory of existing forest values, rather than manage-

[1] We define *exploitation* as the utilization of a resource or value without any overt action to ensure the future supply of that resource or value, either ignoring resource renewal or relying on natural processes to accomplish it.

ing the ecosystem processes that ensure their renewal. The failure of such non-ecological approaches to forest sustainability generally leads, after various periods of time, to an ecologically-based approach. One of the main values delivered by early, "administrative" forest management was generally wood for fuel, timber for industrial purposes, or wood fibre for non-solid wood products. The main emphasis at the start of the subsequent stage in the evolution of forestry (*ecologically-based forestry*) was also on tree growth and wood yield. However, as "modern" societies have developed a renewed interest in other forest values (e.g. wildlife, potable water, non-timber forest products, aesthetics, recreation, many of which were valued by earlier societies), and added concerns about biodiversity, carbon budgets and climate change effects, the need to manage ecosystem processes at both stand and landscape scales to sustain multiple values has become apparent. This leads to the beginnings of what forestry really should be — *ecosystem management*. However, this historical pattern of development from exploitation to ecosystem management has rarely developed in a linear manner, being commonly interrupted by conflicts and social changes, and there are many impediments to true ecosystem management.

How has the development of forestry in Canada reflected this generalized pattern? Many of the First Nations of Canada lived in and depended on forests for their resources and survival. They had a well developed, experience-based knowledge of the forest values they depended on, and practiced either sustainable exploitation or passive/active management of these largely non-timber values. They also practiced warfare to ensure access to forest-based and other resources. Their management involved family or tribal ownership of hunting and gathering areas, while active management involved the use of fire to clear forests, maintain wildlife habitat, promote hunting and food gathering, and/or protect themselves against wildfire and enemies. This continued for thousands of years (Drushka 2003). The arrival in Canada of Europeans brought diseases that decimated many First Nations and resulted in a loss of experienced-based wisdom because of the lack of written language. The acquisition of guns and metal tools altered the First Nations' ability to harvest wildlife and trees, but this was generally balanced by the reduction in their populations. The reduction or elimination of First Nations' use of fire resulted in significant changes in forests in historically fire-dominated areas (MacKay 1979). However, it was the arrival of Europeans that initiated significant and frequently unsustainable exploitation of Canadian forests (Drushka 2003).

Because the colonization of Canada by Europeans began in the east — the closest to Europe — the history of human-induced forest change is longer there than in the west, and the changes in the forests are most apparent (Craig 1988, Frelich 2002). Logging of pine and spruce for ships masts and timbers, and of lumber for export to timber-starved Europe (where forests had been decimated by war, industrial harvest for fuel, and clearing of forests for agriculture) significantly altered the species composition and age-class

structure of eastern Canadian forests, and is thought to have changed the historical natural disturbance regimes associated with insects and fire. This European impact on Canadian forests began in the 1700's in the east, but gained momentum in the 1800's and the early 1900's. Major forest harvesting in British Columbia (BC) did not begin until after World War I, although the gold rush in 1858-1865 brought in 33,000 miners, many of whom found jobs in forestry after the gold rush was over. European settlers on the southern coast of BC in the wake of the gold rush initiated logging of coastal old growth forests in the latter 1800's, and the construction of the transcontinental railway initiated forest clearing and harvesting across BC's southern interior at about the same time. The early industrial logging was driven largely by growing demand for high quality "old growth" lumber in the US Pacific Coast, and export of wood products to the US has continued to be the major driver of forest harvesting and a major contributor to the economy in Canada.

3.2 Canada's lands and forests

Canada is the second largest country in the world, with the third largest area of forest in the world after Russia and Brazil. Canada spans 41 degrees of latitude and 87 degrees of longitude, and has a forest area of 402.1 million ha — 10% of the world's forests and 30% of the global boreal forest (Natural Resources Canada) (Table 3.1). Canada's forests range from temperate deciduous and semi-Mediterranean forest, through savannah, dry and wet temperate conifer forest (including temperate rainforest on the west coast), to subalpine conifer, boreal mixedwoods (deciduous and conifers mixed) and wet and dry coniferous boreal forest. Canada's west coast supports about 25% of the world's extent temperate rain forest (MacKinnon 2003). The western province, British Columbia, accounts for a majority of Canada's total ecosystem diversity — climatic, geological, soils, topographic and natural disturbance regimes, and more than 50% of most measures of the biological diversity associated with this physical diversity. BC has 60% of Canada's vascular plant species, 75% of the bryophyte species, 70% of the bird species, 80% of the mammalian species, and over 60% of the Canadian insect species (Pojar 1993).

Forestry in Canada is mostly under the jurisdiction of the governments of its ten provinces and three territories. The federal government has a network of research centers across the country that are responsible for national inventories and research concerning forest protection, trade, economics and other topics that transcend provincial boundaries, but the actual management of forests for multiple values is provincial/territorial (Table 3.1). Canada also has a network of 14 model forests representing the major forest regions of the country (Natural Resources Canada 2008). Canada's forests are divided into 12 forest regions, each with sub-regions. These represent major climatic and

physiographic subdivisions of the country. There is also a national system of "ecological (biophysical)" land classification (Table 3.1), but forest management at the provincial/territorial level generally employs one of several types of ecosystematic classifications as the ecological foundation for silviculture and stand management (e.g. the biogeoclimatic (BEC) classification of BC (Table 3.1)). The BEC system is one of the most advanced ecosystem classifications specifically designed as the foundation for forest management anywhere in the world, something that reflects the high degree of physiographic, climatic, edaphic, geological and biotic diversity in this western province, and the public ownership of 95% of the forest. In most Canadian provinces some type of ecosystem classification is legally required as the basis for silvicultural and harvesting decisions, which are supported by detailed ecological guidebooks and manuals based on the BEC or similar systems.

Table 3.1 List of some electronic resources about forest management, policy and research in Canada (Websites last accessed on June 15, 2009).

Organization	Topic	URL address
Canadian Forest Service	Forest Research Centers in Canada	http://cfs.nrcan.gc.ca/
	Depository of literature on Canada's forests	http://bookstore.cfs.nrcan.gc.ca
Canadian Model Forest Network	Model Forests in Canada	http://www.modelforest.net/cmfn/en/
Canadian Forestry Association	Climatic and physiographic regions of Canada	http://www.canadianforestry.com/html/forest/forest_regions_e.html)
Natural Resources Canada	Statistical data of the forest sector in Canada	http://canadaforests.nrcan.gc.ca/?lang=en
Nature Serve Canada	Canadian National Vegetation Classification System	http://www.natureserve-canada.ca/en/cnvc.htm
Alberta Sustainable Resource Development	Forest Management at provincial level: Alberta	http://www.srd.alberta.ca/
BC Ministry of Forests and Range	Forest Management at provincial level: BC	http://www.gov.bc.ca/for/
	BC Biogeoclimatic Ecosystem Classification	http://www.for.gov.bc.ca/hre/becweb/
New Brunswick Ministry of Natural Resources	Forest Management at provincial level: New Brunswick	http://www.gnb.ca/0078/index-e.asp
Ontario Ministry of Natural Resources	Forest Management at provincial level: Ontario	http://www.mnr.gov.on.ca/
Sustainable Forest Management Network	Research consortium on SFM	http://www.sfmnetwork.ca/html/index_e.html

Most of Canada's forest land is publically owned, the balance is divided between more than 450,000 private owners. One of the major differences between forestry in eastern and western Canada is differences in the ratio of public to

private ownership of forests. In Prince Edward Island 96% of the timber is cut on private lands, compared with 11–12% in the three western provinces. Newfoundland, the most easterly province, does not fit this trend, with only 3% of the timber harvest from private ownerships (Rotherham 2003). The regional variation in ownerships is a major factor determining variation in forest practices in Canada and throughout North America (FAO 2009). Large areas of government-controlled forest land make the application of ecologically-based regulations easier than where forest ownership is in a large number of small private parcels. However, property rights in public forests can be a major impediment to the development of ecosystem management tenures (Tedder et al. 2002). The diversity of land ownership, forest history, cultures and politics across Canada interacts with the ecological diversity, the components of which were noted above. This requires a region-specific, landscape-specific and stand-level ecosystem-specific approach to forest management, and results in region-specific forest issues in addition to those issues that are common to all of Canada's forests.

3.3 Issues facing forestry in Canada today

Forestry in Canada has advanced to the stage of ecosystem-based management (EBM), but has not yet succeeded in proceeding to true ecosystem management (EM). This reflects the fragmentation of management responsibility for different values on public forest lands between different government agencies, the small size and limited ownership rights on many private forest lands, and the tenure structures on public lands that limit revenue-generating management to timber-related values. All other values are a limitation on that objective. The lack of integrated overall planning (with value trade-off and scenario analysis) and management for all values over landscapes of appropriate extent renders true ecosystem management currently beyond our reach. There are examples where this is not true or only partially true — such as in some community and municipal forests and in Canada's model forests, but it is true for the main forest area, despite the very desirable emergence of ecosystem-based management as a goal across much of the country. Despite great advances towards sustainable forest management and our current status as having probably the best overall management of forests of comparable size and ecological diversity in the world, forestry in Canada faces numerous issues, including, but not limited to, the following (not in any order of priority):

3.3.1 Lack of recognition of the role of natural disturbances

Most of Canada's forests are disturbance-driven: historically by fire, insects and/or wind, and, over the past 200 years in the east and the past 100 years in the west, by timber harvesting (Suffling and Perera 2004). Most of our forests have had some degree of human influence since trees first colonized bare ground following the retreat of the last ice age. The combination of human and non-human disturbance regimes has created landscape level biological diversity in addition to that determined by the diversity of physical environments. By maintaining a shifting mosaic of stand conditions and ages, disturbance regimes have sustained ecosystem productivity, wildlife habitat and biodiversity. Some of the natural disturbances have been altered in scale, frequency and severity by human action firstly by First Nations use of fire (Vale 2002), and secondly by reductions in wildfire over the past 50 to 100 years (Brown and Sieg 1999). Fire control has also been blamed as a major contributor to a vast outbreak of the mountain pine beetle that has decimated more than 7 million ha of lodgepole pine forest in British Columbia (Taylor et al. 2006). Fire control had increased the age of these forests, and, in conjunction with several years of mild winters, had created ideal habitat and survival conditions for this bark beetle. Extensive outbreaks of insect defoliators are a feature of eastern and boreal forest, and there are suggestions that selective removal of certain tree species over the past 150 years may have increased the severity of these outbreaks (Shore et al. 2006).

The key issue related to forest disturbance is the opposition by many environmentalists, and as a result by a large segment of society, to logging. Many insist that this human-made disturbance is bad and that forests should be managed with the lowest levels of disturbance possible, or not at all. Although some of the concerns of environmental groups are justified (such as extensive clearcutting in areas where the historical scale of disturbance has been at a much smaller spatial scale), the non-disturbance view does not respect the ecology of many of Canada's forests, nor does the attempt to replace clearcutting by partial harvesting everywhere. Increasingly, forestry in Canada seeks to balance the desire to emulate the ecosystem effects of historical natural disturbances (landscape patterns and stand characteristics) that have been altered in their frequency, severity and extent by contemporary society, with the rejection by the public of the visual and short-term ecosystem consequences of disturbances that are in fact needed to sustain long-term diversity, productivity and aesthetics. The short-term visual consequences of natural disturbance emulation are frequently interpreted as "ecosystem damage" rather than a necessary part of the long-term ecology of desired values. There is a need for decision support and communication tools that can demonstrate the potential consequences for Canada's forests of deviating significantly from historical disturbance regimes. For a discussion of disturbance ecology, see Attiwill (1994) and Perera et al. (2004).

3.3.2 Need to include climate change effects on forest planning

The need to include strategies of adaptation to and mitigation of climate change effects is widely recognized in Canada (CCFM 2008 (Table 3.1)). Although there have been many estimates of the effects of climate change on Canada's forests, we cannot yet predict with confidence the long-term consequences of climate warming (Redmond 2007). The major effect may be increases in fires and insect epidemics, and possibly some forest disease issues (Bergeron and Flannigan 1995). There will undoubtedly be direct effects on seed production, regeneration, and tree physiology, and in flat topographic areas climatic zones may move significant distances (Hamann and Wang 2006). Recent research has documented migration of tree species in the US (Woodall et al. 2009) and increased rates of tree mortality in the Pacific Northwest (van Matgem et al. 2009), and bioclimatic models have become a widely used tool for assessing the potential responses of species ranges to climate change (Beaumont et al., 2005). However, in more mountainous topography, the effects of climate on determining forest composition are strongly modified by aspect, slope, slope position and soil moisture and fertility. As a consequence, changes in local climate may have rather more subtle effects on the spatial distribution of plant communities than those suggested. The complexity of the interactions suggests that some of the more dramatic pronouncements about "bioclimatic envelope" shifts may only have validity in flatter areas (Hamann and Wang 2006). These authors are revising their predictions concerning ecological zone shifts in British Columbia as a consequence of reducing the error associated with the bioclimatic models they use (Tongli Wang, UBC, pers. com.). Some researchers have criticized the "bioclimatic envelope" approach because it does not represent biotic interactions, evolutionary change and species-dispersal strategies and limitations (Pearson and Dawson 2003). After all, our long-lived species have survived through major climate shifts over the past millennium, suggesting that their ranges may be less sensitive to climatic change than suggested. Climate effects on trees may have more to do with seed production and recruitment of seedlings than with mortality of mature trees, resulting in considerable time lags in changes in tree species distributions. These effects could be explored through ecological models (Nitschke and Innes 2008, Blanco et al. 2009). Until we understand more about climate change effects and their potential variation in different parts of the country, it is difficult to develop coherent forest policy with respect to climate change. One of the tools needed to explore this important and complex topic is ecosystem management models that represent key ecosystem processes, and the effects of climatic variables on these processes.

3.3.3 Need to include carbon budgets in forest management plans

West coast "old growth" forests contain some of the highest stores of carbon of any terrestrial ecosystem. With the public preoccupation with carbon storage rather than with understanding total carbon budgets, the prevailing public opinion is that we should reserve all our old forests as carbon stores, allow younger forests to become older, and protect them from logging, fire and insects (Cannell 1995). Unfortunately this very complex question is generally oversimplified, and results from stand-level carbon inventories and budgets in one type of forest are often extrapolated uncritically to very different types of forest. An essential aspect of carbon budget analysis is the recognition of the temporal scales associated with the changes in forests as sinks, neutral or sources of atmospheric carbon, and there is often inadequate consideration of landscape-level budgets and budgets over longer time spans, although there are encouraging advances in this field (Trofymow et al. 2008). The assumption is frequently made that old forests continuously sequester more carbon, whereas in reality the capacity of forests to act as a net carbon sink generally declines with age as ecosystem respiration begins to equal or exceed primary production and the nitrogen cycle slows down; there is debate over the age at which this occurs (Buchmann and Schulze 1999). Similarly, while several analyses have shown that some undisturbed old-growth forests have significantly greater total quantities of organic carbon than younger managed stands, net annual carbon fixation rates in managed young stands are consistently higher than in old, unmanaged stands (Smithwick et al. 2002). Most in-stand studies in northern temperate forests show that harvesting and replacement of old forest by productive young forest are carbon neutral or slightly negative (Thornley and Cannell 2000) and do not result in significant losses of soil carbon following harvesting (Yanai et al. 2003).

If product replacement (e.g. use of wood instead of steel and concrete — materials that have a greater carbon "footprint") and fossil fuel displacement (unused wood fibre converted to biofuels) are accounted for, harvesting old forest and replacement by younger forest makes a positive contribution to the issue of climate warming. However, the analysis is sensitive to assumptions about long-term storage in the resulting wood products, which led some earlier studies in the US to conclude that the best carbon strategy there is to retain old forests (Harmon et al. 1996).

The issue related to carbon in forests is the tension between advocates of storage vs. advocates of carbon budgets and sequestering — using forests as carbon pumps, not static/declining stores. The debate is complicated of course because old forests offer many other values besides their carbon functions, and these justify the reservation of certain old forests. Also, a focus on carbon stores in many of Canada's forests ignores the periodic release of stored carbon by wildfire (Kurz et al. 2008a, b). What is needed to compliment the work by the Canadian Forestry Service on national carbon budgets (Kurz and Apps

2006, Kurz et al. 2008a) is to drive these budgets by stand-level ecosystem process models linked to life cycle analysis models that track post-harvest carbon storage and fossil fuel displacement.

3.3.4 Lack of understanding of a variety of key ecological concepts

Sustainability, ecosystem resilience, stability and integrity, and biodiversity and "old growth" are all concepts that are part of the foundation of sustainable forest management for multiple values, without an understanding of which forest policy and conservation strategies may fail to meet their objectives and may not satisfy the public's expectations. Inadequate or conflicting understanding of these complex concepts and their operational applicability by some politicians, policy makers, resource managers, researchers, environmentalists and the general public hinders progress. Similarly, the need for site and value-specific management that is based on ecosystem sciences, and the need to practice ecosystem management rather than the management of individual values based on their individual ecologies are not yet widely recognized and accepted in Canada. Ecosystem "health" and "integrity" are discussed in Kimmins (2004). Sustainability is discussed in Nemetz (2007), and forest sustainability in Kimmins (2007).

An interesting recent development in ecology is the growing use of statements such as "ecosystems are complex adaptive systems", and terms such as "emergent properties" (system properties that cannot be deduced from knowledge of individual system components) (Anderson 1972). It seems to us that this reflects the realization on the part of ecologists who had previously focussed on levels of biological organization below that of the ecosystem (individuals, populations or communities) that nature cannot be understood, explained or predicted at these levels without considering their place in ecosystems. This is not new: the great debate about density dependent vs. density independent regulation of populations that raged between animal population ecologists in the mid 20th Century was largely the result of the failure to recognize that ecosystems are complex, that population processes vary with physical environments, and that the future of any level of biological organization can only be successfully predicted in the context of the next true level of integration above: the ecosystem in terms of ecology (Huffaker and Messenger 1964, and Rowe 1961). Population futures are not predictable in particular ecosystems outside of a consideration of all key ecosystem determinants of population dynamics in those ecosystems (see discussion of multi trophic level regulation of populations in Sinclair et al. 2000 and Tscharntke and Hawkins 2002).

The concept of ecosystems as "complex adaptive systems" entails a redundancy. Ecosystems are by definition complex (Tansley 1935), and they are the

"emergent property" of the combination of biological communities and environmental factors. The attribution of the individual-level and species-level concept of "adaptive" to ecosystems is also troubling; ecosystems are neither "born" nor do they die; they do not have a physiology that can acclimate, nor a frequency of genotypes that can become adapted through natural selection. The concepts of ecosystem extirpation or extinction would appear to be a stand-level that refer only to the biota of the ecosystem or to individual species. Stand-level ecosystems are embedded in landscapes of various spatial scales, and have a physical as well as biotic component. It is the meta-populations, meta-communities and meta-ecosystems (the landscapes) that truly define ecosystem function, pattern, stability and resilience (however these are defined), rather than the small scale, local subcomponents thereof. Accompanying these semantic and conceptual difficulties is the variation in the concept of resilience (Holling 1973), which sometimes is defined in the same work as "inertial stability" and sometimes as "elastic stability" (e.g. Puettmann et al. 2009, which uses both definitions). In reality, resilience as inertial stability is a term that refers mainly to the biotic components of the ecosystem because many of the physical and chemical components remain relatively unchanged after disturbance that causes significant biotic change. Resilience as elastic stability involves both biotic and physical/chemical ecosystem processes as ecosystems develop post-disturbance.

Our concern over the possible misuse of such terms is that those concepts that have validity at lower levels of biological organization but not at the ecosystem level may be adopted as the ecological foundation for the management of whole ecosystems and will disappoint us accordingly (Kimmins 2008; Kimmins et al. 2005, 2008). It is time to marry useful stand-level biology and ecology to our understanding of landscapes, and use knowledge of ecosystem dynamics in the face of successional processes and disturbance (Attiwill 1994; Frelich 2002; Perera et al. 2004) rather than develop a new and often redundant set of nomenclature and theory. To explore this topic we need ecosystem-level models that can also be run at population or community levels to investigate the importance for prediction of modeling at the ecosystem level (Kimmins et al. 2008).

3.3.5 Lack of recognition of the complexity of ecosystem-level issues

Politicians, the general public, many environmental groups and frequently forest managers are simply not equipped to recognize, understand and deal with the social and ecological complexity of forestry. As Bunnell (1999) said "forestry is not rocket science — it is much more complex". William of Occam (the source of "Occam's Razor" — a fundamental tenet of science) noted six centuries ago that "theory, explanations and actions should be as simple as

possible, but as complex as necessary", a thought echoed by Albert Einstein more recently — "theory should be as simple as possible but not simpler". Society, science and forestry have all been slow to embrace this important need to recognize and account for complexity.

A problem is an issue that does not get solved; an issue that gets solved quickly is not a problem; problem issues often persist because they are complex and only simple solutions are offered (Kimmins 2008). The current discussion of "complex adaptive systems" is a welcome recognition of ecosystem complexity, but its implementation should be rooted in mainstream, ecosystem-level science of ecosystem function, temporal dynamics and spatial diversity of ecosystems. In Canadian forestry we need policy and management decision support tools that can address complexity at the ecosystem level and marry biophysical forecasts, based on an adequate representation of forest ecosystem complexity, to social desires and needs.

3.3.6 Lack of a landscape perspective and a sufficiently long time scale

There remains a preoccupation with stand-level conditions over short time spans, especially in the minds of the public and certain environmental groups, but also involving some researchers, resource managers and others (Kimmins et al. 2005). The major issues in Canadian forests are generally landscape level and long term, yet there is public antipathy towards licensing forest management institutions to manage large, public forested landscapes over management-relevant and ecologically-relevant time scales. Landscapes are shifting mosaics of changing stands, so clearly the stand level is important. However, the key issues facing forestry transcend stands, and often involve substantial landscapes. Some examples of operational forestry at larger spatial scales in BC can be found in the application of the BEC system in management (Mah and Nigh 2003) or the implementation of management based on natural-disturbance emulation (DeLong 2007). Again, the need is to use ecosystem-based decision support tools that can span ecologically-relevant time and spatial scales (linking stand-level process models with large landscape models), and communicate to a variety of stakeholders our best science-based forecasts (educated guesses) as to the possible outcomes of alternative approaches to forest management.

3.3.7 Using inadequate support tools and predictive models

If all factors affecting the future development of forests remained as they were in the past, traditional, "historical bioassay" population, stand, and landscape

models that reflect the past based solely on experience would be the best type of decision-support tool. However, with changing public expectations for multiple values, changing management methods and changing climates, the inflexibility of simple, experience-based, tree population tools renders them of questionable utility. They should be combined with knowledge-based tools to permit a plausible range of forecasts for changing and uncertain futures for multiple values. Where they are used to support the management of ecosystems for multiple values, they should be ecosystem-level. Models that predict only a single value (e.g. timber or tree growth) based on a single limiting factor (e.g. crown space, light) may be useful for forests in which the selected limiting factor is the only important one and where a single value is the object of the modeling. They are of relatively little value in systems in which there are multiple limiting factors expected to change in the future, and where forecasts must be made for multiple values and permit value trade-off analysis and ecosystem management scenario analysis.

3.3.8 Incorporating public opinion into forest management policies

Fortunately for Canada's forests and their many values, forestry in this country has advanced from an almost totally timber and economics focus to the inclusion of multiple values — cultural, social, biological, environmental and even spiritual — as objectives of management. This evolution has been driven by professional foresters, researchers and environmental groups, and over the last 30 years a consensus has emerged that the public should be involved in the management of Canadian forests (Hamersley and Beckley 2003). The general public has long felt that important issues were not accounted for in forest management, and often the political barriers that frustrated the efforts of foresters and scientists to change traditional forestry required the public action of environmentalists (Wagner et al. 1998). Recent experience has shown that incorporating public opinion and local knowledge can lead to better management decisions, reduced conflict, and greater compliance with sustainable forestry regulations (Hamersley and Beckley 2003). Creation of ecological reserves, parks, reserves of "old growth", wildlife reserves and improved riparian management have contributed to biodiversity objectives, and the sustainability of multiple values has been improved by a policy change to emulate in our landscape harvesting patterns the mosaics of stand ages and composition resulting from past natural disturbance. Not all of these positive aspects of change have occurred everywhere. Sometimes governments are slow to change policy. Sometimes forest companies are slow to recognize the need to change management practices if they wish to retain a social license to operate. Similarly, not all the pressures from environmentalists have been positive, and in some case these have interrupted the evolution of forestry

and returned it to an earlier, less desirable stage (Drews 2008). As noted by Aldo Leopold (1966; p 263) "The evolution of a land ethic is an intellectual as well as emotional process. Conservation is paved with good intentions which prove to be futile, or even dangerous, because they are devoid of a critical understanding either of the land, or of economic land use." Public opinion has to be informed by clear and well-defined indicators of the sustainability of desired values, and about the current state of forest management with respect to these indicators. As Hebert (1999) has stated "Sustainable forest management is really just an attitude. It begins with wants and values, is driven by people and eventual policies, and is fine tuned by science". Spies and Duncan (2009) demonstrated the dangers of forestry and conservation strategies driven by incomplete information and understanding. To assist in communicating choices to various publics and other stakeholders, the ecosystem-level decision support tools mentioned above and later in this chapter need to be linked to advanced, interactive visualization systems (e.g. Sheppard and Harshaw 2000) .

3.3.9 Lack of adequate tenure systems

Hardin (1968) formalized what many people have learned from experience: that unregulated use of a commons leads to unsustainable exploitation. Such over-use of resources has always been the progenitor of forestry. To be sustainable, forestry must be planned, regulated and practised over ecologically relevant spatial (landscape) and temporal scales (minimum of one tree crop rotation or cycle of stand-replacing natural disturbance; preferably several). In the administrative stage of the development of forestry, regulations lack an ecosystem-level understanding of the ecology of resource renewal and sustainability, and in the end they fail. This leads to ecologically-based forestry which, if linked to an ecosystematic land classification (e.g. BC's biogeoclimatic classification (Table 3.1)), may develop into ecosystem-based management (EBM). EBM differs from true ecosystem management (EM) in that no single agency manages all ecosystem components, structures, processes and values. In theory, EBM can become EM by creating a single management plan for the entire ecosystem in a defined forest area, in which a balance of values is managed by using value trade-off and scenario analyses, allowing for a shifting mosaic of conditions and values across the landscape over time. In reality, there are frequently two major impediments to this transition on public forest land: the tenure system and the failure to use multi-scale, ecosystem-level, and management decision support tools. Forest tenure systems vary widely, but in Canada they are generally limited to timber harvesting tenures only, with non-timber values being a constraint on timber objectives. They almost never license the integrated management of ecosystems for a balance of values that varies over time in any place, and varies from place to place according to

the local ecosystem and desired values. Long-term tenures (rotation length or longer) and area-based tenures of ecologically-relevant size have a much higher probability of encouraging stewardship and sustainability of multiple values than short-term tenures and tenures of very restricted spatial extent, but they are not supported by public opinion and often not by environmental groups. Long-term involvement of resource managers within a particular forest area and a single management structure that actively manages all values and their tradeoffs in time and space has a much greater potential to satisfy public expectations for the management of public forests than the restrictive (in time and space and limited to timber management) tenures that generally regulate how public forests are managed today in Canada. Multiple agencies, multiple management/harvesting institutions and no long-term attachment to "place" greatly reduce the possibility of good management compared with alternative institutional arrangements. There are no guarantees of course. Good or bad management can be observed under a variety of tenures — lengths, types and sizes.

3.3.10 Recognizing the role of international trade and economics

Canadian forestry is primarily an export activity — most forest products are traded out of the country, and these products are an important part of our balance of trade and the national economy. The current global economic downturn has reduced the demand for wood products, especially in the US — Canada's major market for forest products (Cashore 1998). This is creating great economic hardship in many forest-dependant communities across Canada (Zhang 2001). "Good" forestry which sustains the diversity of values desired by society is generally more expensive than "bad" forestry. Exploitative harvesting with no management investment is often the most profitable, at least in the short run. It may be difficult to sustain the levels of ecosystem-based forest management that have been achieved in Canada if the economic downturn persists for long. However, promoting the use of certified products, especially by big buyers such as corporations and government contractors, can help to move public opinion towards support for sustainable, ecologically-based forest management.

3.4 How can Canadian forestry respond to these and other issues? One way is ecosystem management modeling

There is no simple answer to this question. It will depend on the issue, the type of forest concerned, and the time and spatial scales at which the issue

is addressed. However, it is clear that many of these challenges are social and political rather than solely biophysical (Spies and Duncan 2009). It is unlikely that the solutions offered will be effective unless they are founded on the best available science, but unless biophysical scientists become more successful at transmitting their science in an understandable and policy-relevant manner, science will continue to be more for science sake than for the solution of problems (Kimmins et al. 2005; Kimmins 2008). A major problem of science is that most of it is conducted at scales of complexity, space and time that are far removed from the issues society faces. To better integrate our current scientific knowledge we can combine our knowledge of the past with our understanding of the present ecosystem structures and processes to develop hybrid experience-understanding decision support tools that are able to project possible futures for the variety of forest values desired by society.

A major risk in modeling is dealing with uncertainty. It is not possible to predict the future with certainty, so modeling in forestry finds its major value in the ranking of alternative scenarios and value tradeoffs and considering possible forest futures — necessary forecasts for policy and practice decision making — rather than making firm predictions. Despite the challenges posed by uncertainty, we continue to use models based on the best available knowledge and understanding because decisions have to be made in spite of uncertainty. Ecosystem-level, multi-value management models offer the best way of dealing with ecosystem complexity, and with changing and uncertain futures for which we have no experience. In order to reduce this uncertainty while maintaining simulation credibility, the use of hybrid models is becoming increasingly popular in forest research and management. Following this approach our research team has developed the FORECAST family of ecosystem-level simulation models.

3.4.1 Hybrid simulation models

Modern forest management calls for managing the whole forest ecosystem at stand and landscape scales, and the dominant trend in Canadian forestry is the emulation of the ecosystem consequences of natural disturbances (Perera et al. 2004). This trend supposes a good understanding of the major processes and interactions between ecosystem components. Simulation models can organise the complexity of information and data into a coherent tool for analysing systems at these various scales (Messier et al. 2003). Many management strategies are undertaken at spatial or temporal scales that make replication extremely expensive if not impossible, therefore modeling is a necessary alternative to empirical experimentation. Also, using forecasts derived from mechanistic simulation models allows forest managers to predict the possible impacts of management alternatives without causing potentially negative effects in real forest ecosystems.

Several ecosystem-level models have been developed (Messier et al. 2003) but in this chapter we focus only on one approach. Process-based models use available scientific knowledge to link several ecosystem variables through equations (Korzukhin et al. 1996), but the difficulty in getting the right coefficients to calibrate those equations can result in unrealistic or unreliable predictions. In contrast, statistical models based on field data usually produce good forecasts if the future management and environmental conditions are similar to those of the past. However, they do not have explanatory powers and therefore cannot be used to explore ecological interactions, generate predictions in areas outside the range of the model's experience base, or predict for futures that are expected to be significantly different from the past (Kimmins 2004). To reduce the shortcomings of both these types of models while maintaining their strengths, hybrid models have been developed. Autecology, population ecology, and community ecology are necessary for the understanding of ecosystems, but they are not sufficient for long-term prediction about ecosystem function. Consequently, these hybrid models should be at the ecosystem level. A more detailed analysis of the philosophy behind hybrid predictors is given in Kimmins et al. (1990, 1999).

3.4.2 The basics of the FORECAST approach: Brief description of the model and its simulation capabilities, and extensions to both landscape and individual tree spatial scales

Since the beginnings of our modeling approach (about 35 years ago), the need to be able to address many of the issues discussed above has resulted in the development of several models, branching out from the earliest one, FORCYTE, and its successor FORECAST (Fig. 3.1). FORECAST is a management-oriented, stand-level, non-spatial forest growth and ecosystem dynamics simulator. It was designed to accommodate a wide variety of harvesting and silvicultural systems and natural disturbance regimes in order to compare and contrast their effects on forest productivity, stand dynamics and a series of biophysical indicators of non-timber values. In FORECAST, empirical input data are used as the basis form which to estimate the rate at which key ecosystem processes (e.g. efficiency of light capture, nutrient cycling, and nutritional regulation of growth) must have operated to produce observed trends in ecosystem productivity and biomass accumulation (see Kimmins et al. 1999, Seely et al. 1999 for further details). These data are entered into "setup" input files and then are processed by the "setup" programs to create the simulation rules and estimates of process rates used to drive the mechanistic, process-based ecosystem-level component of the model. They include (but are not limited to): (i) photosynthetic efficiency per unit of foliage nitrogen based on relationships between foliage nitrogen, simulated self-shading, and net primary productivity after accounting for litterfall and mortality; (ii) nutrient uptake

requirements based on rates of biomass accumulation and literature- or field-based measures of nutrient concentrations in different biomass components on different site qualities; (iii) light-related measures of tree and branch mortality derived from canopy structure input data in combination with simulated light profiles; and (iv) competition among simulated species for resources. The inclusion of these processes provides FORECAST with the capacity to address many of the modeling capabilities discussed above. In addition, in order to address the challenge of simulating climate change effects on forests, direct representation of climate (temperature and water balance) is also included in the version FORECAST-Climate, which includes a new module to allow for simulation of climate change effects on ecosystem processes and values. In order to address different issues at different scales, we have extended FORECAST into several additional applications (Fig. 3.1).

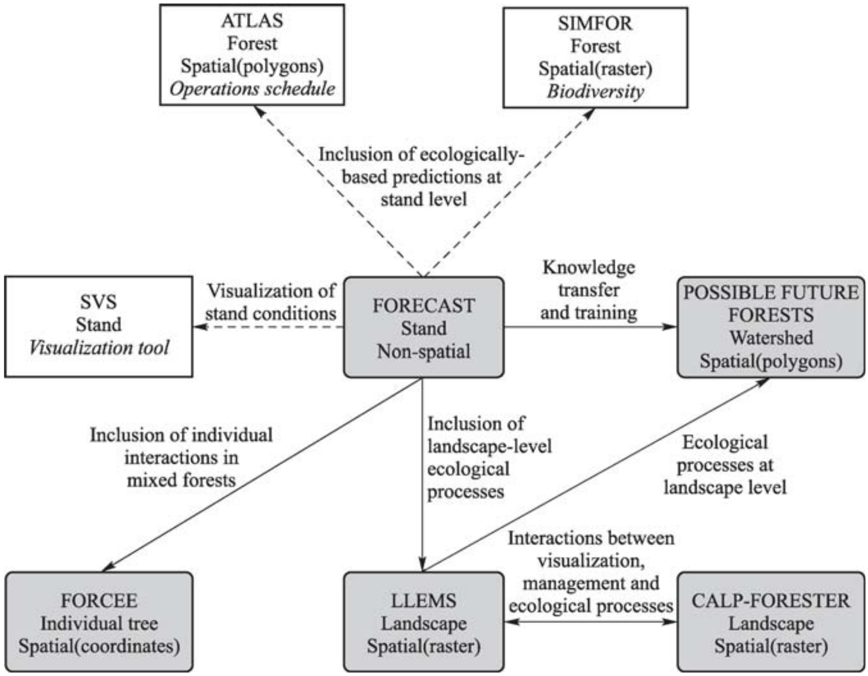

Fig. 3.1 The different models developed by the Forest Ecosystem Simulation Research Group at UBC (boxes with dark background) were developed from FORECAST in order to address the issues indicated by the arrows, and FORECAST output can also be linked to other models.

Ecosystem-level, stand models cannot address all the issues of modern forestry. Landscape-level sustainability and the spatial configuration of ecological processes and the effects of forest management thereon are becoming increasingly important in forest management and conservation. In response, FORECAST has been extended to a spatially-explicit landscape model. This

can simulate plant development and ecosystem processes in user-defined interacting grid cells (that can be as small as 10 m × 10 m) within a framework that can accommodate up to 2 million cells (for a total area of 2,000 ha for 10 m × 10 m cells). In this Local Landscape Ecosystem Management Simulator (LLEMS), cells are clustered into polygons at the start of a run on the basis of a series of attributes (vegetation structure, density, species composition, age, soil condition, and others). This greatly increases the speed of the simulation and permits a high degree of ecosystem process simulation to be applied across the landscape. As the simulation proceeds, individual cells may get transferred to other polygons as the developing vegetation changes light and soil conditions, and as ingress of understory species and tree regeneration changes the plant community. Management actions such as harvesting, planting or fertilization also cause a subdivision of affected polygons to maintain them within user-set levels of heterogeneity. Cells are updated annually or on shorter time steps. This approach permits very detailed spatial process ("bottom-up") simulation over relatively large areas ("top-down") as well as maintaining simulation flexibility in the face of management or natural disturbance. Natural regeneration can be simulated as a consequence of seed production, dispersal and wind effects within and between polygons. Management actions such as harvesting, planting or fertilization also cause a subdivision of affected polygons to maintain them within user-set levels of heterogeneity.

As additional values such as visual quality of landscapes and inclusion of public input into management plans become increasingly important, we have created CALP-Forester as an interface for LLEMS (Fig. 3.2). This tool provides visual output to accompany ecologically-based predictions, and it can facilitate the involvement of stakeholders in management planning by making it easier to visualize possible forest future conditions under different management regimes. LLEMS is well suited to many forestry applications in ecosystem management since it can represent trees, shrubs, herbs (and bryophytes if needed), the independent management of each of these plant life forms and species within life form, site-level management treatments, and the actions of herbivorous animals. It can represent the interactions between trees and understory, and the ecosystem effects of fire, wind or insect epidemic. LLEMS lends itself well to landscape pattern analysis, including carbon budgets or issues of fragmentation and connectivity of wildlife habitats. LLEMS is linked to an interactive 3-D visualization of landscapes of up to 2,000 ha (larger if cell size is increased) with which to communicate the outcomes of the simulation (Fraser et al. 2007).

LLEMS has been developed to address landscape-level issues that are becoming important in sustainable forest management, such as wildlife management and alternatives to clear cutting. Variable retention management (Franklin et al. 2002) is becoming an increasingly popular method employed by forest managers to address non-timber management objectives. The re-

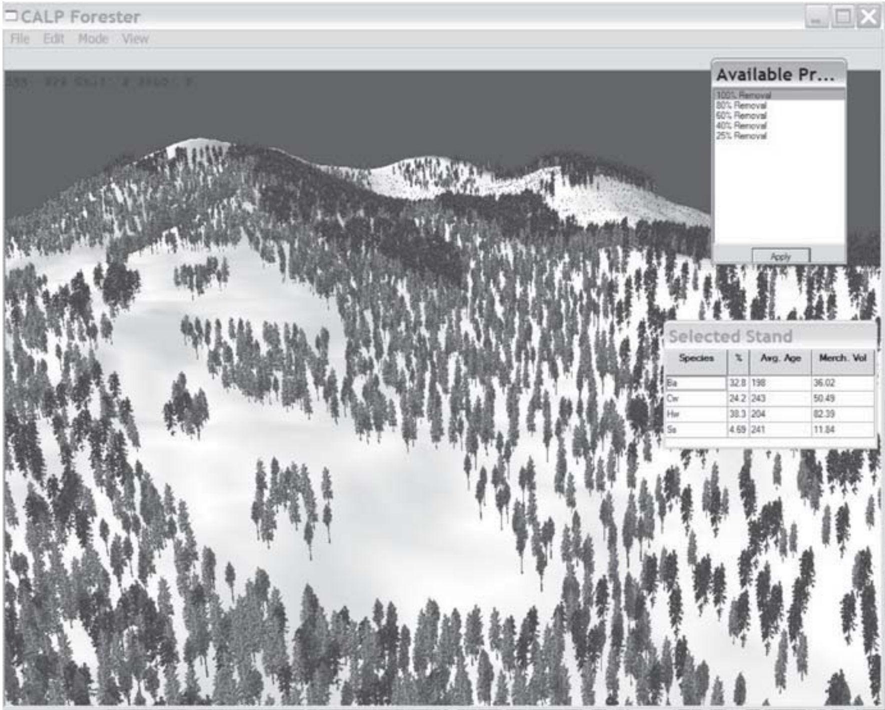

Fig. 3.2 Interactive visualization of LLEMS output: CALP-Forester.

tention of individual trees or groups of trees within a block is intended to maintain structural complexity, to provide habitat for wildlife and to reduce the negative aesthetic impact of timber harvesting (Burton et al. 1999). While it has shown promise in achieving these goals in the short term, the long-term implications of variable retention are largely unknown, and models are needed that can represent the ecological foundations of this new system. Seely (2005) used LLEMS in the coast of British Columbia to study the impact of different levels of variable retention on traditional growth and yield variables (height, volume, biomass) and on several indices of habitat suitability (understory cover, below canopy light levels, number of snags and decomposing logs), demonstrating the capabilities of LLEMS for landscape-level simulation. This use of LLEMS as a decision-support tool for wildlife management has been upgraded with a new module to assess the impacts of management activities at the large cutblock or watershed scale on spatial and temporal patterns of wildlife habitat supply (Seely et al. 2008).

Another important issue in forestry that we have already commented on is the connection between economics, ecology and natural resources values. In order to explore this interaction, we have developed a watershed model, Possible Forest Futures (PFF), designed to simulate small watershed issues that involve the stand-level but with spatially-explicit representation of the

interactions of stands. Such issues in landscape ecology include road construction, harvesting schedules, landscape pattern and riparian forest management, among others. Similar to LLEMS in terms of polygon structure and interaction (but using polygons rather than pixels and minus the detailed light profiling), PFF includes a hydrology model and can track road development. The model also includes extensive output concerning economic costs and benefits, productivity, carbon budgets and values of other social and environmental variables important in modern forestry, the variation of which over time can be examined graphically for individual stands and for the entire watershed. PFF can prepare rotation-length movies of different landscape scenarios for subsequent analyses. Because it is an ecosystem management model that can simulate most aspects of landscape-level issues in forest management, PFF

Table 3.2 Some applications of FORECAST for different forest management issues at different scales.

Research area	Temporal and spatial scale	Ecsosystem type	References
Soil organic matter as indicator of sustainability of forest management	Multi-rotation, stand-level	Coastal Douglas-fir forests	Morris et al. (1997) Seely et al. (2002)
Assessment of the two-pass harvesting system	Stand-level, single rotation	Boreal mixedwoods	Welham (2002)
Sustain or improvement of long-term productivity	Stand-level, multiple rotation	Sub-boreal lodgepole pine	Wei et al. (2003)
Assessment of multi-objective management strategies	Landscape-level, multiple rotations	Boreal mixedwoods	Seely et al. (2004)
Links between different model approaches	Landscape-level, multiple rotations	Boreal mixedwoods	Seely et al. (2004)
Study of yield decline and tree-understory interactions	Stand-level, multiple rotations	Sub-tropical Chinese-fir plantations	Bi et al. (2007)
Productivity across multiple short rotations	Stand-level, multiple rotations	Hybrid poplar plantations	Welham et al. (2007)
Site-specific validation of FORECAST	Stand-level, single rotations	Coastal Douglas-fir plantation	Blanco et al. (2007)
Regional validation of FORECAST	Landscape-level, single rotation	Sub-boreal mixedwoods	Seely et al. (2008)
Complexity needed in ecologically-based management models	Landscape-level, multiple rotations	Sub-tropical plantations and sub-boreal forests	Kimmins et al. (2008)
Landscape effects of forest management for bioenergy	Landscape-level, single rotation	Sub-boreal mixed and planted forests	Flanders et al. (2009)

can also be used to examine land use patterns that include mixtures of forest management, forest reserves and other land uses such as agroforestry and agriculture, and because it is an ecosystem management model, it can simulate most aspects of landscape-level issues in forest management at the small to medium watershed scales.

Continuous-forest-cover forestry and stands with complex vertical and horizontal structure have been embraced by the public as the right way to manage forests. This is a response to the aesthetic and other consequences and to the even-age structure of stands resulting from clear-cut or shelterwood silvicultural systems. While low disturbance systems fall within the natural range of variation for some Canadian forest types, they are not characteristic of many forests that have developed with stand replacing natural disturbance in which even-age and monoculture are natural, sometimes temporary but sometimes persistent conditions. Models are needed urgently that can explore the consequences of accepting this public pressure and changing the fundamental disturbance ecology of many forests. Of necessity, such models must represent the key ecosystem processes that are being altered. In response to this need we have developed FORCEE, an individual tree, spatially explicit model, in which the spatial coordinates are known for each individual tree, and any configuration of tree distribution and density can be represented. The model simulates nutrient cycling, light profiles, and patterns of litterfall for each tree, and their effects upon growth of adjacent trees and understory. Rules for the simulation of plant growth and interactions are derived from the FORECAST model and applied to individual trees with additional input data on individual plant dimensions in different competitive environments. As a derivative of FORECAST, FORCEE can examine the limiting factors of light, water and nutrients.

3.5 Conclusions

Forestry in Canada has advanced from unregulated exploitation, through timber-focused administrative forestry, to ecosystem-based forestry in a remarkably short period, considering the size, the ecological diversity of its forests and its social and political diversity. Change in forestry comes slowly because the political and administrative structures and legislation controlling it and the investment structure financing it have an inertia that takes time to adjust. In the minds of the public, change is even slower than it really has been because the visual consequences of past policies and practices are very persistent on the landscape. In fact, under pressure from the public (that built on frequently unrecognized earlier work by academics, researchers and foresters conducted before there was an active environmental movement in Canada), change has been active for at least three decades. Forestry in Canada today is amongst the best in the world, the most rooted in ecosystem

sciences, and the most regulated relative to the size and diversity of the country. Many challenges remain, and our forestry remains a significant distance from what it could be. In order to assist all the sectors involved in development of landscape-level ecosystem management, appropriate modeling tools must be developed, tested and used. Given the ecological diversity as well as the complexity of forest ecosystems, diverse forest modeling approaches are needed to address the diverse questions of forest management in Canada, and linking them together will be one of the challenges for future ecological research.

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